IMPERIAL INSTITUTE

MONOGRAPHS ON MINERAL RESOURCES WITH SPECIAL REFERENCE TO THE BRITISH EMPIRE

PREPARED UNDER THE DIRECTION OF THE MINERAL RESOURCES COMMITTEE WITH THE ASSISTANCE OF THE SCIENTIFIC AND TECHNICAL STAFF OF THE IMPERIAL INSTITUTE

CHROMIUM ORE

BY

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IMPERIAL INSTITUTE

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A special staff is engaged in the collection, critical revision and arrangement of all important information respecting supplies of minerals especially within the Empire, new methods of usage and other commercial developments.

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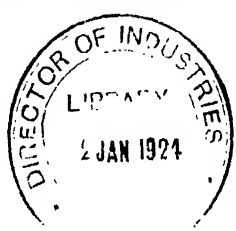

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PREFACE

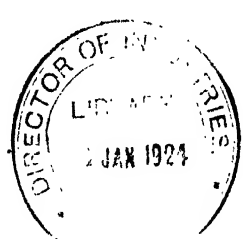
THE Mineral Resources Committee of the Imperial Institute has arranged for the issue of this series of Monographs on Mineral Resources in amplification and extension of those which have appeared in the *Bulletin of the Imperial Institute* during the past fifteen years.

The Monographs are prepared either by members of the Scientific and Technical Staff of the Imperial Institute, or by external contributors, to whom have been available the statistical and other special information relating to mineral resources collected and arranged at the Imperial Institute.

The object of these Monographs is to give a general account of the occurrences and commercial utilisation of the more important minerals, particularly in the British Empire. No attempt has been made to give details of mining or metallurgical processes.

HARCOURT,
Chairman, Mineral Resources Committee.

IMPERIAL INSTITUTE, LONDON, S.W.7.
Nov. 1920.



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CHROMIUM ORE

CHAPTER I

CHROMIUM ORE: ITS OCCURRENCES, CHARACTER AND USES

INTRODUCTION

THE importance in the steel industry of chromite, the only ore of chromium, partly as a source of chromium, and partly as a basic refractory, has been brought into prominence in recent years, and especially during the war period, by an increased and urgent demand for the ore.

In former years large supplies of chromite were obtained from deposits near Brusa in Asia Minor, and in 1908 a production of as much as 27,937 long tons was reported; but the output from this source dwindled chiefly in consequence of developments in Southern Rhodesia and New Caledonia, which countries have been responsible for by far the greater part of the world's output in recent years.

In pre-war years Germany imported chromite from both Southern Rhodesia and New Caledonia, and the shutting off of these sources of supply left her mainly dependent on Asia Minor.

By far the best customer for the chromite of Southern Rhodesia and New Caledonia, however, was the United States, whose domestic production prior to the war was so small as to be comparatively negligible. After the outbreak of war there was very active prospecting and development in the United States and other parts of North America; but

in spite of this the United States of America continued to suffer from the shortage of supplies, for although her output in 1916 was 47,000 tons (compared with 255 tons in 1913), her imports for the same year amounted to 114,655 tons. Canada profited largely from this shortage in the United States up to the cessation of hostilities, and the proximity of the Quebec deposits to the eastern markets of the United States, as compared with that of the Californian and Oregon deposits, will doubtless tend to favour the Canadian product in future.

The ample shipping facilities that prevailed during the pre-war period made it possible for Southern Rhodesia and New Caledonia to meet most of the world's requirements, and prices continued low. The transport difficulties and increased demand for the ore during the war had a marked effect on prices, which in this as in many other instances rose to an abnormally high figure, and stimulated much prospecting and development in localities which either did not repay attention in pre-war days, or which yielded only small outputs. Canada with its increased output from 121 tons of chromite in 1914 to 32,790 tons in 1917, furnishes a good example of this tendency. India increased its output from 5,888 tons in 1914 to 57,773 tons in 1918.

Much of this recent development will probably have only temporary results as regards output, but the result on the whole has been to add largely to our knowledge of the world's chromite resources.

The cessation of hostilities in 1918 was followed by a reaction in the chromite industry due to a suddenly-arrested demand for chromite for military purposes, and also to the accumulated stocks of the mineral in the United States. The absorption of these stocks and other circumstances have had the effect of reducing prices and restricting production as compared with the war period, but it should not be long before the industry settles down to normal conditions.

Ores of Chromium

Chromium does not occur naturally in the metallic state. It is a constituent of a number of minerals of which only *chromite*, known also as chrome iron-stone or chrome iron ore, is important as an ore of chromium. Pure chromite ($FeO.Cr_2O_3$) should contain 32 per cent. of ferrous oxide and 68 per cent. of chromic oxide, but the iron and chromium in this mineral are usually in part replaced by magnesium and aluminium, sometimes to a very considerable degree.

Iron ore sometimes contains from 1 to 3 per cent. of chromium, and is then known as *chromiferous iron ore*. This ore, however, is more important for its iron constituent than for its chromium contents. Considerable quantities of chromiferous iron ore are mined in Greece and Cuba, but in each case the ore contains small percentages of nickel which imparts special qualities to the steel produced from it. In the manufacture of this steel, the chromium contents are in part intentionally oxidized and removed in the slag.

Other minerals containing chromium are *picotite* (chrome spinel), *crocoisite* ($PbCrO_4$), *chrome diopside*, *chrome garnet*, and *chrome mica*, but these are of no value as ores.

Chromite proper is blackish-brown in colour when freshly fractured, and gives a brown streak. It has a sub-metallic lustre, a hardness of about 5·5 and a specific gravity of from 4·32 to 4·57. It crystallizes in octahedra.

The following are some typical analyses of chromite ores from various sources [2].

Locality.	Cr_2O_3.	FeO.	MgO.	Al_2O_3.	SiO_2.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Baluchistan	57·0	13·6	16·6	9·8	1·2
Selukwe (Rhodesia)	46·5	15·7	11·7	15·5	8·0
Canada	46·0	22·5	4·9	8·9	7·7
Russia (Urals)	55·8	21·6	13·9	3·3	5·4
Hungary (Orsova)	39·0	16·1	17·2	17·5	8·0
Asia Minor	60·1	15·7	16·4	6·3	1·1
U.S.A. (California)	43·7	14·0	16·5	16·0	8·0
U.S.A. (N. Carolina)	57·8	25·7	5·3	7·8	2·8
New Caledonia	54·5	17·7	8·0	11·1	3·1

Chromite is widely distributed in the form of disseminated grains and lenticular or irregular masses associated with serpentine. Many of these are of little or no value owing to their low-grade character or remoteness from transport facilities or to both these drawbacks. Even where conditions are otherwise favourable, the irregularity of rich chrome-ore masses and their tendency to merge into low-grade ore or barren country rock makes their mining and development a very uncertain matter. The masses are frequently lenticular or pockety, and an ore mass may therefore pinch out quickly, as a result of which there may be much barren work before another ore mass can be found.

Sands, gravels and surface detritus, derived directly from the disintegration of chromite-bearing serpentines, sometimes contain a considerable percentage of chromite, but only in rare instances are these of any importance as commercial sources of chromite.

The chromite deposits of Southern Rhodesia, New Caledonia, India and Asia Minor contain ores rich enough to be shipped as mined, but those of the United States, Canada and most other countries require dressing to yield an exportable product.

The table on page 5 shows the world's production of chrome ore from 1912 to 1919 inclusive.

Diagram 1, on page 6, and Diagram 2, on page 7, graphically show the outputs of chromium ore for the years 1910–17 for the world and British Empire and for the four principal producing countries respectively.

Valuation and Prices of Chromite

Prior to the outbreak of war, the market for chromite was practically restricted to high-grade ores, and, for most purposes, only ore containing 50 per cent. of chromic oxide or upwards was accepted. The price was based on a 50 per cent. standard of chromic oxide, and the New York purchasers paid about 15 dollars a ton for 50 per cent. ore, and 50 cents per unit for each unit above 50 per cent. Grades lower than 50 per

World's Production of Chromite Ore *

In long tons (2,240 lb.)

—	1912.	1913.	1914.	1915.	1916.	1917.	1918.	1919.
United Kingdom	—	—	99	—	—	—	—	—
India	2,890	5,676	5,888	3,768	20,159	27,061	57,773	31,504
New Caledonia [1]	50,688	62,351	41,325	[2] 56,550	[2] 72,924	[2] 41,218	26,000	—
Southern Rhodesia	61,840	56,593	43,042	54,090	79,349	65,146	27,936	31,501
Canada	—	—	121	11,019	24,568	32,790	19,637	7,443
Australia	473	677	648	757	451	1,343	718	246
Bosnia	197	300	207	—	—	—	—	—
Greece	6,364	6,240	6,946	10,252	9,721	6,642	10,715	—
Russia	20,035	—	—	—	—	—	—	—
Japan	1,567	1,289	2,049	2,805	8 147	8,860	7,128	—
United States	201	255	591	3,280	47,034	43,725	82,355	3,900
Totals	145,155	133,381	100,916	142,611	262,353	226,725	232,262	—

[1] Mineral Industry.

[2] Statistics of Iron and Steel and Allied Trades Federation.

* Except where otherwise stated, statistics given in this monograph are from official sources.

cent. of chromic oxide found a limited market, chiefly as a refractory, but at prices which offered little inducement to producers.

The demand for chromite created by war conditions brought

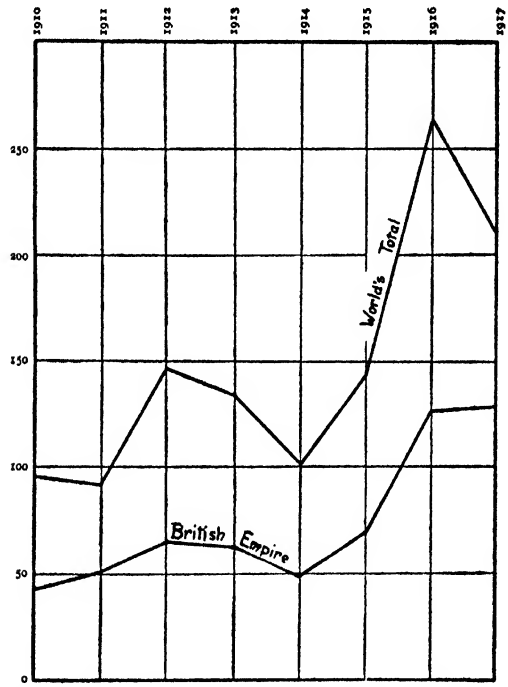


DIAGRAM 1.—OUTPUTS OF CHROMIUM ORE IN THOUSANDS OF TONS (2,240 lb.)
Note.—For some additional information see table on page 5.

about a great change in the market for this mineral, and not only did prices of the high-grade ores rapidly increase, but lower grade ores found a ready market at remunerative prices, thus giving producers of all grades an opportunity of benefiting by the situation. The table on page 8, taken from the Report

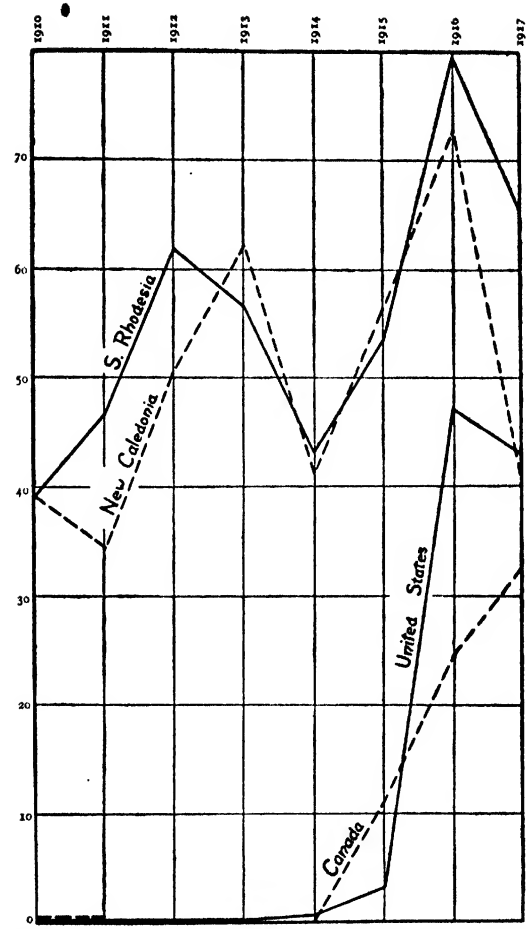


DIAGRAM 2.—OUTPUTS OF CHROMIUM ORE IN THOUSANDS OF TONS (2,240 lb.)

Note.—For some additional information see table on page 5.

of Mining Operations in Quebec, 1915–16, strikingly illustrates this change [3]:

Percentage Cr_2O_3.	Prices December 1915. Per long ton.	Prices December 1916. Per long ton.
	$	$
25	14·00	18·00
30		22·50
35	16·00	27·50
40	18·00	33·00
45	20·00	38·00
50	25·00	45·00

In July 1918, ores with a minimum of 45 per cent. of chromic oxide were quoted at $1·55 per unit.

The prices of chromite ore at the mines also correspondingly increased. As an example, the Annual Statements of the Trade and Shipping of the Union of South Africa show that the prices per ton f.o.b. Beira for Rhodesian chromite in recent years were returned at the following averages: 1914, 43*s.* 1*d.*; 1915, 47*s.* 6*d.*; 1916, 76*s.* 10*d.*; 1917, 89*s.* 3*d.*; and 1918, 68*s.* 6*d.* Since 1918, the prices of chromite have been appreciably reduced, and quotations have been more or less nominal.

The equipment of mines generally with modern and efficient plants would assist producers to meet competition at the more normal prices.

Mining of Chromite

The method of mining chromite necessarily varies according to the nature of the deposit. For primary deposits the open-cast or quarry method is generally best adapted for mining this mineral. Where large ore deposits occur, as at Selukwe, in Rhodesia, and these deposits are well defined, underground workings are practicable and may be advantageous, but where the deposits are chiefly of the disseminated type of ore, and exist in small disconnected bodies, it is apparent that open-cast methods of working are preferable. In any case, a large amount of lean or barren rock must be

mined in order to expose the payable bodies of ore, and the mining and disposal of this waste rock is generally a costly operation in chromite ore mining.

When the quarry method is used, it is usual to work with a series of benches or terraces at different depths. The broken ore is raised to the surface sometimes by means of cable derricks, at other times by inclined tramways.

Where the workings are on high ground, that is, not less than 200 or 300 feet above the general surface level, it is often practicable to drive an adit under the workings from the side of the hill, and to have one or more rises to them. This arrangement permits of the broken ore being passed down to the adit and trammed away instead of being hoisted. Such an arrangement also provides drainage, which is of importance.

Chromite and its associated rocks are less hard than quartz, but do not break so readily owing to their tougher character. Blasting is necessary, and considerable judgment on the part of the miner is called for in order to obtain the best results, perhaps more than in general mining: most mines of importance employ machines for drilling, and the duty of a medium-sized machine per shift of eight hours may be taken at about 40 feet. The average amount of rock broken per lb. of low-power explosive used is from 4 to 5 tons.

The rock, if mixed with waste material, is sorted where broken to some extent, the best being put aside for direct shipment, but usually the mixed material is sent to the surface and sorted there.

Concentration of Chromite Ores

Hand sorting has already been mentioned, and this includes cobbing, which consists in separating a piece of ore from an adhering lump of waste by means of a hammer. The larger pieces of rock are usually coarsely broken in a jaw-crusher and then passed on to a revolving table or an endless belt for hand sorting. There is always a quantity of "fines" which cannot be thus separated, and there is also the mixed material obtained when disseminated ore is mined, which can only be concentrated by mechanical means.

Concentrating by gravity machines involves a preliminary breaking followed by a moderately-fine crushing of the ore, which is effected, in many cases, by the use of the Californian drop stamp, but modern plants are more usually fitted with pebble or ball mills of either the cylindrical or Hardinge type.

The crushed material with the necessary water is passed to some form of table concentrator, of which the Wilfley is typical, and is separated into :

1. *Concentrate*, consisting of chromite chiefly.
2. *Middling*, containing considerable quantities of chromite.
3. *Tailing*, low in chromite contents and sent to waste dump.
4. *Slime*, often rich in chromite in a fine state of division, which seldom pays for further treatment.

The middling is re-treated, usually on another table, which results in a further recovery of chromite, but the final tailing and the slime contain chromite, representing an appreciable loss. This loss cannot be entirely avoided, but can be minimized by preliminary sizing and careful operating.

The concentrate obtained varies in quality according to the care exercised in the various operations, but usually contains about 50 per cent. of chromite.

Utilization of Chromite

One of the most important applications of chromite ores is in the production of ferro-chrome alloys used in the making of chromium steels, which are steels containing about 2 per cent. of chromium. The production of chromium steels by starting with a chromiferous iron ore containing a small percentage of chromium, although apparently feasible and easy of accomplishment, presents difficulties, which add considerably to the cost of production.

Early in the history of the chromium steel industry, a Tasmanian company erected blast furnaces and other plant with a view to utilizing the large deposits of chromiferous iron ore found in that country, but the difficulties, encountered in the process and in afterwards realizing the product, resulted in

the failure of the company [5/p. 460]. Since that time large quantities of chromiferous ores from Greece and Cuba have been successfully treated for producing steel, but in each case the ore contains a small percentage of nickel so that the final product is a chromium-nickel steel of a special quality. The general practice in making chromium steels is to use, as an intermediate product, ferro-chrome alloys rich in chromium, and to mix these with ordinary carbon steel in a molten condition, and thus to produce a steel containing the desired proportion of chromium [1].

Ferro-chrome alloys, which are made by the reduction of high-grade chromite ores or concentrate, were originally reduced in clay crucibles at a cost which prohibited their use, except for very special purposes. The modern practice is to reduce the chromite in electric furnaces, a method which has greatly cheapened the product and extended the use of these alloys. Ferro-chrome alloys always now contain over 60 per cent. of chromium. These alloys tend to take up large proportions of carbon in their manufacture, which is regarded as an undesirable constituent, the quality and price being determined in inverse proportion to the carbon contents.

The London quotations for August 1917 for the different qualities of ferro-chrome with a base of 60 per cent. chromium illustrate this point [6].

Percentage of carbon.	Price per long ton. £. s.
8 to 10	70 0
6 „ 8	72 10
4 „ 6	75 0
2 (maximum)	160 0

Chromium steels have valuable and special properties, amongst which are the following: They possess great hardness allied to extreme toughness; they can be bent cold if the operation is slowly carried out; they can be welded to iron, to form either a hard surface, or a core impermeable to the finest drilling tools.

Steels containing either chromium alone, or chromium alloyed with one or more of the metals nickel, vanadium,

tungsten and manganese, are used for armour-plate and armour-piercing projectiles, burglar-proof safes, magnet steel, cutlery, bridge steel, tyres, axles and springs in the railway and automobile industries, stamp-mill shoes, crusher jaws and internal parts of ore-crushing machinery subject to abrading action. A steel containing from 5 to 6 per cent. of chromium is said to be non-rusting, but the steel known commercially as "rustless" usually contains 13-14 per cent. of chromium, 1 per cent. of nickel and carbon very low. This steel is impervious to oxidation by water, air and certain acids and is chiefly employed for the blades of "rustless" cutlery [7].

Certain special alloys of chromium have come into use in recent years. One is the alloy known as "stellite," which varies in composition within certain limits, but is essentially an alloy of cobalt and chromium with tungsten or molybdenum. The chromium contents are from 10 to 12 per cent. This alloy takes a good cutting edge and is specially suitable for high-speed tools. It possesses the useful property of retaining its hardness and a cutting edge at a temperature approaching a red heat, so that a tool made from this alloy can be run at a speed at which ordinary carbon steel tools would be softened by the heat generated. This property also permits the use of the tool for a comparatively long time without grinding, and thus adds considerably to its efficiency. It is thus the first serious rival of steel. It also possesses the property described as "rustless" in a very high degree and is not attacked by organic or nitric acids. For the latter reason it is found suitable for many articles of equipment in chemical works and laboratories [8].

Another alloy known as "nichrome" has recently created considerable interest. Its composition is 60 per cent. nickel, 14 per cent. chromium and 15 per cent. iron. Its special use is as a high-temperature resisting alloy, and as such it has an extremely long life as compared with that of iron or steel. It is used for annealing boxes, carbonizing boxes, retorts, and conveyor chains in operation at high temperatures. It is also utilized for pyrometer tube covers [9/p. 449].

According to F. J. Griffiths, chromium-vanadium steel holds a position virtually at the head of the commercial alloy

steels, owing to the extremely wide range of physical qualities it can develop by proper heat treatment [9/p. 450].

Chromium magnet steel is sometimes used as a substitute for tungsten steel [9/p. 445].

According to C. A. Edwards and H. Kikkawa, chromium in conjunction with carbon is the cause of the great hardness of hardened high-speed steels, and it materially lowers the temperature at which these steels can be air-hardened [10].

Stainless steel, besides its employment in cutlery, is used in the manufacture of exhaust valves for aeroplane engines, turbine blades, pump rods and valves, acid pumps, rams, cotters, evaporating pans, races and rollers for bearings, steam traps, etc. In the electrical field it is used for permanent magnets, and for electric heating-stoves and utensils [11].

The employment of chrome ore by the steel works as a refractory material for lining and repairing basic hearth furnaces either in the form of chrome bricks or more or less irregularly shaped blocks as mined, accounts for a very considerable proportion of the ore produced. It is said to have advantages over ordinary refractory material such as magnesite and silica-alumina mixtures, not only in possessing a longer life and being of less ultimate cost, but for its superior properties in resisting corrosion, retaining a fair degree of hardness at high temperatures, resisting abrasion and withstanding sudden temperature changes. Chromite being of a neutral character, also possesses special value as a refractory in certain cases where basic or acid refractories would be undesirable. It is anticipated that chromite ore will find increasing use as a refractory, especially in high temperature metallurgy [12].

The use of chromite in the chemical industry is of great importance, as it is the source of chromium for the manufacture of the chromates and bichromates, chromic acid, chrome yellows and greens, so extensively used in a large number of industries.

The soluble chromates and bichromates probably find their greatest application in the dye industry, not so much as direct dyes, but as mordants for fixing and producing "fast" colours with coal-tar dyes in wool, silk and also

certain printed cotton goods. It is also used in dyeing khaki material.

A further application of these salts is in the tannage of certain leathers known in the leather trade as "chrome leathers." These were formerly leathers of the lighter kinds, such as glacé-kid, calf-kid and glove leathers, but the term now includes a much wider range. Chrome-tanned leather is noted for its waterproof and other qualities.

Bichromates are used for bleaching oils and fats, and are well known as important oxidizing agents in laboratory work.

Chromic acid, chrome yellow and chrome green are chiefly used as pigments in decorative painting and also in the ceramic industry. They form the colour base of many beautiful pigments and glazes.

Evidence of the importance of the trade in chromium chemical compounds is furnished by the Annual Statement of Trade of the United Kingdom with Foreign Countries. This statement shows that the exports of chromates and bichromates for the six years ending 1918 averaged 94,965 cwt. per annum.

For the five years ending 1915, the United States imported from various parts of the world the following average annual quantities of chromium compounds:

	lb.
Chromates and bichromates	27,750
Chromic acid	6,763
Chrome yellow and chrome green	135,541

During the same period, according to J. S. Diller, the average annual importation of raw chromite ore into the United States was 61,558 long tons, of which it is estimated that a larger proportion was used chemically than metallurgically [13].

CHAPTER II

SOURCES OF SUPPLY OF CHROMIUM ORE

(*a*) BRITISH EMPIRE

THE chromite deposits of the British Empire include some of the largest and richest known. Those of Selukwe in Southern Rhodesia have for some years yielded a larger output than any others, and the more recently discovered chromite deposits of Lomagundi in the same country may possibly prove to be of commercial importance also.

In 1917, the production of the Canadian chromite mines exceeded 30,000 tons of ore, and it is believed that many new chromite deposits await discovery in the Quebec and other serpentine areas of the Dominion.

Newfoundland possesses large bodies of chromite ore from which a commercial product can be obtained by concentration.

The Indian chromite deposits are scattered over several provinces; their joint production in 1918, which probably is capable of great expansion, reached about 58,000 tons.

The Transvaal contains large undeveloped deposits of chromite which may prove to be important contributors to the world's output.

New South Wales, Queensland and New Zealand all possess numerous deposits of chromite. The small production from these in past years gives little indication of their latent resources. On the whole, the Empire's reserves of chromite appear ample to meet any large demand for many years.

EUROPE

United Kingdom

Serpentine deposits are found at various localities in Scotland. One of these is at Corrycharmaig, 4 miles W.N.W. of Killin Station, Loch Tay. A road leads to within half a mile of the mine. The mine is situated on the slopes of a hill called Dun Garbh Beag, which consists of epidiorite. Several small quarries and one drift were opened many years ago by a former Marquis of Breadalbane, but work was abandoned after about 60 tons of ore had been removed. The chromite appears to be disseminated through the serpentine and no vein is to be seen. Analyses of some specimens made in the Laboratory of the Cleveland Steel Works in 1884, gave the percentages of chromic oxide at 37·18 and 38·79.

On the island of Unst, Shetland, serpentine outcrops over a large area, and appears to carry more or less chromite disseminated throughout with occasional masses or segregations of considerable size. On the north side of Balta Sound, some thousands of tons of ore were said to have been mined prior to 1845 and again, on a small scale, as recently as between 1913 and 1917. The deposits, while of considerable extent, appear to contain only small quantities of ore of payable grade [14/pp. 33–5]. The following are two analyses of Unst chromite given by Heddle:

No.	Cr_2O_3.	FeO.	MnO.	Al_2O_3.	CaO.	MgO.	SiO_2.
1	44·56	17·52	0·50	23·74	1·29	—	11·09
2	48·03	18·08	trace	16·55	·88	16·61	·83

ASIA

British North Borneo

A sample of chromite from Malliwalli Island examined in the Scientific and Technical Department of the Imperial Institute was found to contain 51·21 per cent. of chromium sesquioxide. A chromite sand also occurs at Marasinsing Beach.

Ceylon

Alluvial chromite has been found in the Bambarabotuwa district and in several other districts of Ceylon, but no commercial development has been reported.

India

Chromite has been found to occur in the peridotite rocks of the "Chalk Hills" near Salem, Madras, and also in the Andaman, but so far no attempts have been made to work it. It is found in the Quetta-Pishin and Zhob districts of Baluchistan, and production has continued since 1903, averaging from 1909 to 1915 about 3,000 tons per annum, and rising to 22,944 tons in 1918. The ore occurs in veins and irregular segregated masses in the serpentine which accompanies the great basic intrusions of Upper Cretaceous age, amongst the hills bordering the Upper Zhob Valley, both to the north and south, and there are indications that these deposits may continue along the Lower Zhob as far as the Tochi Valley.

A deposit occurs about two miles east of Khanogia in the Pishin district as a vein-like mass of rich ore about 400 feet long and of an average breadth of 5 feet. An analysis of this ore by the Geological Survey showed it to contain 54 per cent. of chromic oxide. This locality is connected by a good road with the railway station at Khani, from which it is about 17 miles distant.

In Mysore State, chromite deposits occur in the districts of Mysore, Hassan and Shimoga, but work has been confined to the first two districts. The most important of the Mysore deposits is situated near the village of Kadakola in the Mysore district. The country consists of gneiss, with occasional patches of hornblende-schist. It is cut by two ultra-basic dykes of the dunite series, one of which has been completely altered to serpentine for a length of about two miles. The chromite occurs for the most part as a narrow vein, not exceeding an average of from 9 to 12 inches in width, but there is also a large lens-like body of the ore. Some of the ore in

this deposit is of distinctly good quality, containing up to 52 per cent. of chromic oxide, but it is believed that a considerable proportion is of lower grade [15]. This deposit has yielded some thousands of tons of ore, and is still being worked.

Chromite deposits occur in the Hassan district extending over a length of about 20 miles in a matrix of talc-serpentine, the result of the alteration of an original tremolite-enstatite rock. The deposits are irregular and pockety in character. The ore consists for the most part of small grains of chromite embedded in the matrix and is not of high grade.

The chromite deposits in Shimoga district occur near Harenhalli. The ore occurs as grains in a talcose matrix, and the grade of the ore does not exceed 35 to 40 per cent. of chromic oxide in the richest specimens. This deposit has not been worked, and it is doubtful if it possesses economic value [16]. Operations in Mysore have been largely confined to the Kadakola deposits. In 1909 the output from this area was 4,727 tons. On account of low prices, mining was suspended until 1912, in which year there was a small production, and eight prospecting licences for chromite were issued.

In the Singhbhum district (Bihar and Orissa), a deposit of chromite occurs in veins and in granular form in serpentine. This deposit has been worked in recent years and a few hundred tons were produced up to 1915. In 1918 the quantity of ore mined was 1,086 tons.

In July 1914, the Baluchistan Chrome Co., Ltd., was registered in England to acquire leases of chrome areas covering 6,159 acres in the Hindubagh district of Baluchistan. A railway from Khanai to Hindubagh has been constructed, and shipments commenced in March 1917.

In the Bombay Presidency, 60 miles from Ratnagiri, large outcrops of chromite occur associated with serpentine. Some of these outcrops are stated to be 1,000 feet long and 300 feet wide. Specimens assayed about 34 per cent. of chromic oxide.

The total output of chromite for India for eight years ending 1918 is given below, the respective tonnages for Baluchistan, Mysore and Singhbhum being also shown [16] [17].

Year.	Baluchistan.		Mysore.		Singhbhum.		Totals.
	Long tons.	Value.	Long tons	Value.	Long tons.	Value.	Long tons.
		£		£		£	
1911	3,804	5,072	nil	—	nil	—	3,804
1912	2,890	3,849	nil	—	nil	—	2,890
1913	3,414	1,162	1,414	821	848	452	5,676
1914	3,006	1,052	2,330	1,258	552	301	5,888
1915	2,161	2,161	1,041	1,088	565	282	3,767
1916	7,620	7,620	9,802	6,280	2,737	2,495	20,159
1917	15,659	15,659	8,136	7,446	3,266	3,111	27,061
1918	22,944	22,944	33,740	27,474	1,085	1,644	57,769

AFRICA

Southern Rhodesia

A large deposit of chromite ore occurs in the neighbourhood of Selukwe, in Southern Rhodesia, and since 1906, when 3,308 tons of this ore were produced, this deposit has yielded a very large tonnage.

The following statistics taken from Reports of the Rhodesia Chamber of Mines [4], show the production of the mineral since 1910:

Year.	Long tons.	Year.	Long tons.
1910	39,287	1915	54,089
1911	46,752	1916	79,349
1912	61,839	1917	65,145
1913	56,593	1918	27,933
1914	43,042	1919	31,501

The most important deposits of workable chromite ores in Rhodesia have hitherto been those of the Selukwe district, and the whole of the production is stated to be in the hands of Rhodesia Chrome Mines, Ltd., an English-controlled company.

The large extent and commercial importance of these deposits justify a more detailed reference than can be given to less significant occurrences of the mineral, and the following particulars, abridged from a description of the Selukwe deposits by A. E. V. Zealley [18], deal with the most striking features.

The types of the chromite containing rocks in this area are:

1. *Talc schist.* This is the most important.

2. *Carbonate and carbonate talc schists,* which are varieties of the above.

3. *Chloritic schists.*

4. *Serpentines.*

5. *Silicified serpentines.*

The chromite is found in the talc schist and serpentine formation, which is an irregular narrow body, widening at its northern end where the mine and the town of Selukwe are situated. The occurrence of chromite in talc schist is unusual, for in other parts of the world occurrences of chromite are described as being associated with olivine or rhombic pyroxene or serpentine. Nevertheless, serpentine containing chromite does exist at Selukwe, although this is of less importance than the deposits found in the talc schist.

The serpentines at Selukwe appear to be metamorphosed peridotites. In some places they show a schistose structure. Chromite is always present with, usually, hæmatite and chlorite.

Chromite is distributed through the talc schists and serpentines in disseminated crystals and grains, but at certain places, notably in the talc schist and silicified serpentine, it occurs massive in the form of lenses. At the mines at Chrome Hill, the chromite is in whitish speckled talc schist, which is not always pronouncedly schistose, and is usually siliceous. It occurs also in ferruginous silicified serpentine. As a rule, the chromite bodies are situated near the margin of the talc-schist-serpentine formation, and occasionally they pass into the adjacent formation.

Over 130 lenses of chromite ore have been mapped on the surface at various points, and the bulk of these range from 150 to 450 feet long. But a much larger number of smaller bodies outcrop, which have not been indicated on the map.

The chromite bodies, although distributed throughout the mass, tend to form close aggregations. The most important of these appears to be that of the Chrome Mine, where eight or ten large bodies are being quarried, and up to 1914 had yielded upwards of 300,000 tons of crude ore. In several other parts of the talc schist area, large aggregations of chromite bodies

appear, and there are also a number of smaller, but important aggregations within this area. There are few parts of the north and east portions of the talc schist area in which chromite is not present, and there are reported to be occurrences of enormous bodies of low-grade chromite in serpentine and talc schist alongside the Umtebwe Valley immediately north of the Selukwe mineral belt.

The known occurrences of chromite ore in other parts of the world are in rocks less metamorphosed than those of Selukwe, the latter being so highly altered that it is difficult to determine to what extent the ore may have been modified by alteration processes. There does not seem to be any reason in this instance to depart from the generally accepted theory of magmatic differentiation.

The large number and exceptional dimensions of these chromite ore-bodies and the aggregation referred to, make the conditions for mining unusually favourable. The transport facilities, with a direct railway to Beira, from whence the ore is shipped, are also good, and although the value of the ore marketed up to 1915 was only about £3 per ton, out of which mining costs and a railway freight of £1 per ton from Selukwe to Beira had to be met, the producers of this ore were not only able to compete with large producers in other parts of the world, but to a considerable extent secure their markets.

The Selukwe chromite is of good, but not of exceptionally high grade, as compared with that obtained from other sources.

The nature of the deposits and the large dimensions of many of the ore-bodies have enabled crude ore to be shipped, no concentration being necessary. There is a large quantity of lower grade ore, which will probably not be exploited so long as abundant high-grade material is available, but later the former may become of importance.

Chromite deposits occur in several other parts of Rhodesia, including Lomagundi, Victoria and Makwiro. In regard to the Lomagundi occurrence, the *Mining Journal* of November 2, 1918, quotes the *Rhodesia Herald* to the effect that the deposit is on the Umvukwe Ranch, thirty miles from Banken Junction, and extends over 4,500 acres, the ore occurring it

eight parallel lines in serpentine. The average content of over 300 samples was 53 per cent. of chromic oxide. There is also stated to be a large amount of chromite sand which can be dressed up to 45 per cent. of chromic oxide [19].

The Makwiro deposits in the " Great Dyke " running north and south through Southern Rhodesia from the Zambesi River almost to the Limpopo, are reported to be of large extent but of a grade much inferior to the Selukwe deposits.

The accompanying table gives a summary of recent exports of chromium ore from Southern Rhodesia, in long tons [20].

Table of Exports of Chromium Ore

Exports to	1912.	1913.	1914.	1915.	1916.	1917.	1918.	1919.
United Kingdom .	1,526	2,751	2,074	6,905	7,302	16,650	25,779	4,532
France . .	19,258	12,348	7,069	2,046	5,350	—	—	—
Norway . .	...	—	6,600	7,300	5,800	2,000	—	2,892
United States .	32,500	24,500	22,192	37,748	59,450	34,300	8,000	9,821
Belgium . .	2,427	3,418	1,861	—	—	—	—	—
Germany . .	2,167	8,312	3,579	—	—	—	—	—
Holland . .	3,564	4,829	2,244	—	—	—	—	892
Other countries .	—	—	—	40	138	15	16	131
Totals . .	61,442	56,158	45,619	54,039	78,040	52,965	33,795	18,268

Union of South Africa

Natal

Chromite has been found in serpentine on a farm at Tugela Rand, near Krantz Kop, and specimens analysed were found to contain from 25 to 28 per cent. of chromic oxide.

No chromite mining appears to have been attempted, probably because the grade of the ore is too low to make this successful.

Transvaal

Chromite has been located on the De Kroon Farm, about twenty miles west of Pretoria, and is found within serpentinized pyroxene rocks. The ore, which carries about 35 per cent. of chromic oxide and traces of gold and platinum, is somewhat difficult to concentrate, and its commercial

exploitation on any considerable scale is therefore unlikely [21/pp. 82–3].

In the eastern part of the Transvaal, chromite has been found in the Lydenburg district in a more or less continuous chain of outcrops along the margin of the Bushveld Plutonic Complex. The belt of country in which these outcrops occur is about 1½ miles wide, and the ore has been found in ten different localities. It occurs in fairly well-defined bedded veins up to 5 feet thick with a dip 8 to 15 degrees in a westerly or south-westerly direction. The chromite is usually associated with a black, heavy, highly-basic hypersthenite.

Chromite deposits also occur in the Rustenberg district of the Central and Western Transvaal, along a more or less well-defined zone situated at an average distance of 5½ miles north of the crest-line of the Magaliesberg Range, and extending over a length of about 28 miles, from a short distance north-west of Rustenberg, through the farm Kronendaal, to as far eastwards as the Crocodile River. The country rock is, on the whole, less basic than that of the Lydenburg district, and olivine-bearing rocks or serpentines have so far not been met with in this area.

One of these deposits, which is typical of all the others, forms a well-defined bar about ten yards wide on the surface, composed of dark, hard, rather compact, lustrous chromite, showing a slight tendency to banding on the weathered surface.

The Transvaal ore consists of a black, lustrous, fine-grained aggregate of granular chromite which easily weathers to a friable rock and becomes readily disintegrated into sand.

The following are analyses of the chief constituents of ores from three different localities [22] :

Locality.	No.	Cr_2O_3.	FeO.	Fe_2O_3.	MgO.	Al_2O_3.	SiO_2.	CaO.
Kronendaal . . Western Transvaal	1	36·16	41·35	—	5·91	9·26	3·08	2·10
" "	2	35·30	19·60	2·10	13·45	13·70	12·70	2·05
	3	37·03	23·95	0·71	9·94	17·23	7·63	2·00

It will be seen that these analyses represent somewhat low-grade material, and if they can be regarded as typical, it is

not probable that this ore will be exploited while so much of better grade is obtainable.

Platinum in amount from 1 dwt. to the ton downwards has been found in chromite from Kronendaal near Rustenberg, but such small quantities are scarcely likely to prove of importance.

Samples of chromite from deposits in Secocoeniland were found to contain from 40 to 45 per cent. of chromic oxide, and up to 1·5 dwt. per ton of platinum, and other samples sent to the Imperial Institute from Jacktlust were found to contain from 47 to 38·4 per cent. of chromium sesquioxide. Possibly these deposits will be of considerable importance in the future. When some of the richer and more accessible deposits in other parts of the world have become exhausted, which is inevitable, these large bodies of lower grade material may be sought for and developed, but at present it is doubtful if they could be exploited with any hope of profit.

West Africa (Togoland)

A discovery of a chromite ore deposit was reported by Koërt in 1908. This deposit is situated near the line from Lome to Atakpame and the existence of other deposits is regarded as highly probable [23].

NORTH AMERICA

Canada

Chromite is found in the eastern township of the Province of Quebec in the neighbourhood of Coleraine, Thetford and Black Lake, and this appears to be the only district from which chrome ore has been produced.

The ore occurs as irregular pockets and masses as well as in streaky and disseminated form in Cambrian serpentines.

Only a comparatively small portion of the chromite-bearing area has been explored, and on this account mining operations have hitherto been confined to open cuts and other shallow workings. There is reason to think that this region contains one of the largest developments of chromite known, but a large

proportion of the ore requires to be dressed to yield a marketable product [24].

Representative samples of Canadian chromite yielded the following results by analysis [25]:

No. of sample.	Cr_2O_3.	Al_2O_3.	SiO_2.	MgO.	FeO.	CaO.	Total.
1	51·03	12·16	5·22	16·32	13·06	2·61	100·40
2	53·07	8·01	6·44	16·08	15·27	1·20	100·07
3	55·06	- -	1·60	—	21·70	--	—
4	65·16	7·48	—	—	27·36	--	99·9
5	49·75	11·30	—	18·13	21·28	—	100·46

In 1905 and 1906, the annual production from these deposits was between 7,000 and 8,000 long tons, but by 1914 this had fallen to 121 tons. It suddenly revived in 1915 to 11,019 tons, to 24,568 tons in 1916, to 32,790 tons in 1917, and to 19,637 tons in 1918, most of which was exported to the United States. However, this tonnage included a considerable quantity of low-grade ore containing only from about 30 per cent. to 35 per cent. of chromic oxide (Cr_2O_3) [26].

The improvement in the prices realized for chromite due to war conditions stimulated the producers in Quebec to great activity, and many old workings were opened up and production revived.

The Mutual Chemical Co. of Canada reopened certain old workings and erected a concentrating plant with a production-capacity of from 12 to 15 tons per day of concentrate containing about 50 per cent. of chromic oxide. In the same district an old mill formerly belonging to the Black Lake Chrome and Asbestos Co. was renovated and used as a customs mill, producing concentrate of over 50 per cent. grade, which was shipped to the United Chemical Co. of America.

In August 1915, the Fletcher Pulp and Paper Co., of Sherbrooke, began work on a chromite property in the township of Orford, and made a few shipments that year. In 1916 work was actively continued and several hundred tons of ore were shipped. The main workings consist of an open pit which had reached a depth of 75 feet.

The chromite occurs in lenses in the serpentine, and the

deposit is situated on the top of a hill one mile north of Lake Webster. Samples of serpentine in the chrome-iron region gave from 0·73 to 6·32 per cent. of chromite. Dykes of granite in the serpentine appear to exert a favourable influence upon the deposition of the mineral [21/pp. 25–6]. The ore is conveyed on sleds to the shore of the lake, where it is loaded on wagons. These are ferried across the lake to the road, over which the ore is carted to Sherbrooke, a distance of 13 miles.

The Bennett and Martin Chrome Mines have worked several prospects on the property of the King Bros. in Ireland township, north of Coleraine Station, with satisfactory results, a considerable quantity of both high-grade chromite and crude asbestos having been mined and shipped. The main workings are on Lot 28, Range 1, where, in an opening 300 feet long and 10 feet wide, several lenses of chromite occur.

The Dominion Mines and Quarries is operating the Montreal Pit, Lots 25 and 26, Range II, of Coleraine, from which low-grade ore is being shipped, and the same company is also working another mine on Lot 16, Range A, Coleraine.

The Black Lake Asbestos and Chrome Co., which was the largest producer in 1916, mined on Lots 27 and 28, Range B, of Coleraine. The rich ore was sent direct to consumers, but the remainder was sold to the Mutual Company of Canada, and was concentrated at the Black Lake Mill.

J. V. Bélanger, of Black Lake, worked on Lot 19, Range X, of Coleraine, and employed thirty men for six months. Most of his ore was sent to the Mutual Chemical Co. for concentration.

A small deposit of chromite has been located on the northern slope of Taylor Basin in the Bridge River district, British Columbia. It is an interesting fact that it contains small diamonds which, after extraction, break up into still smaller fragments.

A chemical analysis of this ore made by the Mines Branch of the Geological Survey of Canada, showed the presence of 48·72 per cent. of chromic oxide [27]. No information is yet available as to the value of this deposit as a source of chromite ore.

At the Mastodon claim, in the Grand Forks Mining Division, small lenses of chromite occur, striking N.W. and S.E., which are nearly perpendicular, and from 10 feet to 20 feet long, 6 feet thick in the middle, and 10 feet deep. About 670 tons of ore, averaging 38·5 per cent. of chromic oxide, were shipped from this property in 1918 [28/p. 205].

On Scottie Creek, near Clinton, chromite, associated with serpentine, occurs in a peridotitic belt apparently about one quarter of a mile in width and striking N.E. No ore was shipped from this deposit in 1918 [28/p. 227].

In 1911, chromite and platinum were reported by the Geological Survey as occurring in varied quantities on Olivine Mountain, Tulameen district, but they are nowhere present in sufficient quantity to warrant diamond-drilling exploration [28/p. 214].

The fact that chromite deposits are practically confined to serpentine areas clearly indicates the localities in which prospecting for the mineral is most likely to lead to success, and a useful purpose might be served by some reference to the various districts within the Dominion in which occurrences of serpentine have been reported.

Serpentine masses occur in Canada in the Laurentian, Huronian and Cambrian formations.

The Laurentian serpentines are confined to formations of that age which cover the greater part of Eastern Canada, its most easterly occurrence being near Pisarinco Cove, New Brunswick. Farther west there are occurrences in the Ottawa Valley in the townships of Grenville and Templeton; in the Seigniory of La Petite Nation which adjoins the Grenville township, and still farther west crossing the Ottawa River. Serpentines exist in the township of Ramsay, Lanark County, Ontario, about 30 miles south-west of the township of Templeton, in the townships of Dalhousie and South Sherbrooke, and also at North Burgess, adjoining Dalhousie township. Serpentines are reported to occur about 20 miles farther south in the township of Loughborough, Frontenac County, at Wollaston on Hatchet Lake, and at the head of Reindeer Lake. A. C. Lawson, of the Geological Survey, reports serpentine in the Keewatin area on the west side of Lake Teggau, a tribu-

tary of Rainy Lake. Another mass of serpentine occurs on South Bay, Lake Despair.

The Huronian serpentines are of more limited extent than the Laurentian. According to investigation by the Geological Survey, serpentine of Huronian age occurs at two points in Charlotte County, New Brunswick, one north-east, and another two miles north of St. Stephen. Chromic oxide is a constituent of these serpentines, but no chromite deposits have yet been reported in them. In a north-westward direction from the above, serpentine outcrops at Lake Abitibi and on a small island in the middle of Pigeon Lake have been reported.

The Cambrian serpentines are found in the great serpentine belt that extends from Southern Vermont to Gaspé, in the Province of Quebec. This belt is conveniently divided into three areas:

1. That including part of the townships of Bolton, Orford, Brompton Melbourne and Danville.

2. The Thetford-Black Lake district, covering part of the townships of Ham, Wolfestown, Coleraine, Thetford and Broughton.

3. The area including part of the Gaspé Peninsula.

It will be seen that these serpentine masses are numerous and widely distributed through the eastern part of the Dominion, and although productive mines of chromite are at present confined to the Thetford-Black Lake district, in Quebec Province, and no large workable deposits have been reported outside this locality, there is reason to expect that exploration will reveal the presence of such deposits in some of the numerous districts in which serpentine areas exist.

It appears that in 1919 only one operator in Quebec was producing, but as normal shipping of chromite from Rhodesia and New Caledonia is gradually resumed it may be anticipated that the mining of Quebec ore will be on a considerably reduced scale as compared with that during the war period. In 1919 the total shipments were only equivalent to 3,446 long tons of chromic oxide. No ferro-chrome has been produced recently [30].

Exports

The following table gives recent Canadian yearly exports of chromium ore :

(In long tons, 2,240 lb.)

	1911.	1912.	1913.	1914.	1915.	1916.	1917.	1918.
Total Exports *	. 15	12·5	—	533	6,509	11,279	17,168	14,134

* Exports are not quoted prior to 1915. [29]

Note :—The figures for 1911–14 represent chromite imported into United States from Canada.

NEWFOUNDLAND

There are chromite deposits on the west coast at Bluff Head, Port au Port Bay, 30 miles from Sandy Point, and at various inland localities. The country rock is stated to be a diorite, traversed by numerous broad belts of dark green serpentine, which contain the chromite deposits.

The chromite in these deposits appears to occur in comparatively large bodies, one such body being described as 97 feet in length and about 8 feet in width. The ore when mined breaks in large angular masses, the parting between the masses being thin bands of serpentine. The analyses of samples from the different exposures gave a range of from 39 to 50 per cent. of chromic oxide, but the content generally is too low for producing a high-grade material without mechanical dressing of the ore.

From 1896 to 1899, 5,500 tons of ore were mined. Most of this was shipped to Philadelphia, and a considerable quantity used for the manufacture of refractory bricks for lining furnaces.

By close sorting and cobbing, an effort was made to produce a high-grade product containing not less than 50 per cent. of chromic oxide, but the results were not regular. Subsequently concentration works were erected, and it has been shown that the ore can be dressed to yield concentrate of good quality, but production appears to have been suspended for some years [21/p. 73].

A deposit has been reported to occur at Benoit Brook, at some distance from the coast. Another deposit is referred

to as occurring near the head-waters of the Bay d'Est and Gander Rivers.

A small amount of platinum is stated to be present in some of the Newfoundland chromium ores.

AUSTRALASIA

Australia

Two of the states of Australia are small producers of chromite, recent outputs being shown in the following table:

Production of Chromite in Australia

In long tons (2,240 lb)

	1912.	1913	1914	1915	1916	1917.	1918.	1919.
New South Wales	22·5	500	618·5	638·5	450·5	586·5	368	250
Queensland	450·5	177	—	119	—	750	232	—

New South Wales.—The deposits of chromite in this state first began to receive attention in 1882, and as a result of active prospecting in 1893 ore was discovered in over sixty localities.

The first production of ore was from the Bowling Alley Point deposits situated near Nundle, Peel River, where it occurs in quantity as an outcrop about 700 feet above the Point. Analyses of samples of this deposit made in 1892 showed from 37 to 47 per cent. of chromic oxide.

Other deposits occur at Pueka, Gordonbrook, Clarence River, about 30 miles north-west of Grafton. They are found chiefly along the junction of the serpentine and the rock into which the latter has intruded. Pockets of ore 12 feet by 12 feet and 24 feet by 18 feet have been located. These deposits were worked in 1891 and again in 1895 to a small extent, but only about 30 tons of ore were exported. No doubt, the fact that much of the ore is disseminated through the serpentine and would require dressing before being shipped, has influenced production, and a further deterrent is the long team haulage of 24 miles to the nearest navigable point on the Clarence River.

During recent years, deposits at Mount Lightning in the Gundagai district have furnished the bulk of the chromite produced in New South Wales. These deposits, which are situated about four miles north-east of the Coolac railway station, were first opened in 1892, and produced 2,000 tons of ore in 1895. These yield an ore of good grade, some of the deposits containing chromite assaying from 49 to 56 per cent. of chromic oxide.

The production of chromite in New South Wales, which in 1899 amounted to 5,242 tons, had dropped to 23 tons in 1912; since then a few hundred tons have been produced annually.

Queensland.—Chromite has been found in the belt of country from Keppel Bay to Marlborough in numerous small patches spread over large areas, such patches not containing in any case over 100 tons of ore.

Chromite is reported to occur at Pine Mountain, 7 miles N.N.W. of Ipswich and 31 miles from Brisbane. It occurs in the form of very small irregular masses in a belt of serpentine [31/pp. 421–3].

Deposits of considerable size are reported to occur north and north-east of Rockhampton, in one case between walls of limestone and serpentine. Two analyses of this ore show 48 and 32·9 per cent. of chromic oxide respectively.

Another deposit in this district, 3½ miles south-east of Tungamull railway station, consists of lenses and irregular shaped masses separated from each other by serpentine. An analysis of the ore shows 36·6 per cent. chromic oxide [31/p. 421].

The *Queensland Government Mining Journal* for March 1918, p. 113, reports that the Black Lode Chrome quarry, near Canoona in the Rockhampton district, produced, in 1917, a quantity of chromite amounting to 750 tons. Of this, 530 tons were sold and despatched to Mount Morgan, Cloncurry, New South Wales, South Australia and Tasmania, the principal purchaser being the Mount Morgan Co., which bought 360 tons. The destinations of this ore suggest that it was purchased as a refractory for furnace lining.

In 1918, the production from the above quarry amounted to 350 tons only [32].

Victoria.—The only deposit of chromite so far reported in Victoria is that on the southern branch of the Wellington River, Gippsland. This occurs about a quarter of a mile east of the junction of Thele's Creek with Dolodrook Creek.

Masses of ore have been found over an area of 50 acres, but lack of transport facilities probably accounts for the fact that no production has yet taken place.

Western Australia.—No chromite is produced from this state, but a chromiferous iron ore occurs at Comet Vale, North Coolgardie. The ore has the following percentage composition: ferric oxide, 79·01; chromic oxide, 5·30; silica, 3·14; phosphorus, 0·078; and sulphur, 0·124.

No development of this ore-body has yet been reported.

Tasmania.—Chromite is known to occur in the Pieman alluvial of the North Dundas tin-field, and in all the creeks which flow away from the basic rocks of the locality, but no production of the mineral has been reported.

In the Ironstone Hill near the River Tamar at Port Lampriere, large deposits occur of a brown hæmatite containing about 3 per cent. of chromic oxide and but little sulphur and phosphorus. These deposits have been described by Chas. Gould, Government Geologist, and H. M. Johnstone in his *Geology of Tasmania* also refers to them as being of large extent [33].

In the immediate vicinity of these deposits is a great mass of serpentine in which there are extensive outcrops of ironstone pointing to the existence of large deposits of hæmatite or magnetic iron ore beneath.

New Zealand

There are several deposits of chromite in New Zealand, none of which appears to be worked at the present time.

One deposit, which has been known for a good many years, and from which a small quantity of ore was produced in 1901 and in 1902, is situated at Onatea, Croiselles Harbour, where the ore occurs in elliptical masses 1,200 feet above sea-level.

Other more important chromite deposits occur associated with the magnesian rocks of the Dun Mountain mineral belt

of the Nelson district. The Dun Mountain rises to a height of 4,000 feet above sea-level and occupies an area of about four square miles. The mountain is composed largely of massive olivine, in which chromite occurs uniformly disseminated as fine grains and occasionally in large masses. Chromite has been mined or prospected in no less than sixteen different parts of this area, but the quantity of ore mined has not been great. The quality of the ore mined may be gathered from the analyses of samples from four different workings: Chromic oxide per cent.—(1) 27·40; (2) 32·32; (3) 53·64; (4) 31·46.

Deposits occur at Jackson Saddle as a number of lenses of poor quality in laminated altered peridotite. The analyses of samples from two of the largest lenses showed 21·8 and 34 per cent. of chromic oxide respectively.

At the head of Chromite Creek, some old chromite workings exist; also in the hills east of the Serpentine stream, but no chromite *in situ* is now visible in the decomposed serpentine.

Near Little Ben Nevis, which lies just outside the Dun Mountain sub-division, a number of old chromite workings exist in which the ore-bodies are, in some cases, still visible. These ore-bodies, however, are not of great extent.

Chromium ore has been found from D'Urville Island to the gorge of the Waivoa River. The chief developments of the ore are found between the Upper Matai Valley and the Lea River, a distance of 12 miles. Chromite deposits occur in the Lake Harris Range at Milford Sound and also at Moke Creek, Otago.

Production of chromite in New Zealand has never been large, and appears to have been suspended entirely for some years past [21/p. 81].

CHAPTER III

SOURCES OF SUPPLY OF CHROMIUM ORE

(*b*) FOREIGN COUNTRIES

MANY important chromite deposits occur in countries outside the British Empire. New Caledonia has only lately yielded the position of premier producer of chromite to Rhodesia. The Asia Minor deposits are extensive and the product of high grade. These are by no means exhausted. Russia is rich in chromite deposits and was formerly a large producer. The temporary suspension of production will probably not be of long duration. Greece has been a steady producer of chromite for many years, and in 1916 was still able to export 9,880 long tons of the mineral [34].

Of lesser importance are deposits in Austria, Hungary, Germany, Norway, Bosnia and Macedonia, but most of these are capable of being developed into important producers, if circumstances are favourable. Central America is also reported to contain large chromite deposits, and it is said that in one district the ore is used as a building stone. Large chromite deposits are reported in Brazil, and a considerable production has recently been commenced.

The United States possess chromite deposits both west and east, and also in Alaska. The Californian deposits are well known and have long produced ore on a small scale. After the outbreak of war, and the consequent difficulty in obtaining chromite for home requirements, the production of ore in the United States reached about 80,000 tons per annum against a former annual output of a few hundred tons. This affords a striking example of the possibilities of production latent in many of the neglected or undeveloped chromite deposits of the world.

EUROPE

AUSTRIA

Although serpentine occurs in many localities in Austria, chromite is not found in abundance. In Upper Styria, near Kraubach, the ore has been worked in the Gulse Valley where it occurs irregularly in small bunches and stringers which have been developed by means of open cuts [43/p. 684]. It usually requires concentration to bring it up to a marketable standard.

The accompanying tables summarize the imports and exports of chromite ore of the Austro-Hungarian Empire for the four years preceding the war:

Imports of Chrome Ore into Austria-Hungary, 1910–13

In long tons (2,240 lb)

Imports from	1910	1911	1912.	1913.
Greece	—	153	52	—
Germany	270	125	109	83·5
Turkey (European)	348	143·5	126	246
,, (Asiatic)	67	695·5	—	—
British Possessions in Africa	—	—	—	9·5
United Kingdom	—	—	747	—
Australasia	255	—	3,225	2,460
Portugal		1,052	—	—
Other countries	310	12	—	—
Total	1,250	2,181	4,259	2,799

Exports of Chrome Ore from Austria-Hungary, 1910–13

In long tons (2,240 lb)

Exports to	1910.	1911.	1912.	1913.
Belgium	9 5	—	—	—
Germany	114	69	93	139
Greece	—	—	—	1
Russia	14·5	—	—	—
Total	138	69	93	140

Note:—Statistics are not available for later years.

GERMANY

A large deposit of chromite is found in Lower Silesia on the southern slope of Mount Zobten between Schweidnitz and Jordansmuehl. The ore-body which occurs in serpentine was 23 feet thick at the surface and increased in magnitude as greater depth was gained. The composition of the ore is from 35 to 42 per cent. of chromic oxide, from 19 to 22 each of ferric oxide and alumina, from 3 to 5 per cent. of silica, and from 16 to 18 per cent of magnesia. Some work formerly was carried out on this deposit, but had been discontinued for some time prior to the outbreak of war owing to the unsuitability of the ore either for refractory material or for chemical purposes [21/p. 75]. It is quite probable that the urgent need for chromium arising out of the war led to the reopening of this deposit, but no particulars are available.

In Upper Silesia, veins of chromite traversing serpentine exist in the vicinity of Frankenstein, but their exploitation had not, prior to the war, been a commercial success.

The accompanying tables show the export and import trades of Germany in chromium ore for the four years preceding the war. More recent information is not available.

Imports of Chromium Ore into Germany, 1910–13

In long tons (2,240 lb.)

Imports from	1910.	1911.	1912.	1913.
Turkey	6,703	1,716	2,645	2,168
British E. Africa	997	—	—	—
Portuguese E. Africa	992	1,960	2,652	3,991
United States	—	492	1,222	—
French Australasia	13,312	9,873	13,519	13,266
Other countries	1,081	1,722	2,790	3,452
Total	24,075	15,763	22,828	22,877
Value 1,000 mk.	1,258	829	1,197	1,200

Exports of Chromium Ore from Germany, 1910–13 *

In long tons (2,240 lb.).

Exports to	1910.	1911	1912.	1913.
Belgium	51	1,468	101	—
Switzerland	1	—	415	334
Austria-Hungary	—	—	91	95
Other countries	327	298	158	241
Total	379	1,766	765	670
Value 1,000 mk.	26	140	96	73

* Including nickel ore. [35].

GREECE

At Volo and at Pharsala in Greece, important deposits of chromite exist associated with serpentine rocks, but the ore is of moderate grade containing about 40 per cent. of chromic oxide. These deposits have yielded for some years past a considerable, if irregular, output of ore. The productions from 1911 to 1918 inclusive have been as follow.

Year.	Long tons.	Year.	Long tons.
1911	4,540	1915	10,252
1912	6,364	1916	9,721
1913	6,240	1917	6,643
1914	6,945	1918	10,718

The ores occur in irregular segregations and in lenticular bodies in fissures in Cretaceous limestones, as at Thebes and Lokris, or as contact deposits between the serpentine and limestone, as at Tsouka, Karditza, Lutza and probably Pavlorado. The percentage of chromic oxide in Grecian ores rarely exceeds 50, and for this reason they are used more for refractory material than for making ferro-chrome or bichromates. The percentage of silica in some specimens is as high as 8 [43/p.690]. Chromite deposits occur in the province of Saloniki [43/p. 698].

In the states of Lokris and Boitio on the east coast, and on the islands of Euboea and Skyros, are large deposits of a chromiferous iron ore which are being worked on an extensive scale.

These ores contain from 46 to 52 per cent. of iron and from 2 to 3 per cent. of chromium, with small percentages of nickel and cobalt [36].

The production of these ores is entirely for export, and has diminished considerably since the outbreak of war, but for 1912 and 1913 the exports were 370,842 and 305,116 long tons respectively. A large proportion of this output was shipped to the United Kingdom. The Annual Statement of the Trade of the United Kingdom shows the quantities imported for the six years up to the end of 1918 as follow [37]:

Year.	Tons.	Year.	Tons.
1913	217,142	1916	69,629
1914	194,006	1917	51,973
1915	105,370	1918	43,439

A steel produced from Greek chromiferous iron ore analysed chromium, 0·32, nickel, 1·41, cobalt, 0·25, and manganese, 0·93 per cent. [5].

Eastern Hungary

Chromite occurs in payable quantities in serpentine at Orsova. The ore is of low grade, shipments averaging about 40 per cent. of chromic oxide. It occurs in an extensive area of serpentine on the left bank of the Danube, and has been worked to a small extent by means of open cuts at Ogradina Dubova, Plavishevitza, Tsoritza and Eibenthal [43/p. 685].

No recent information regarding chromite production is available.

Norway

Chromite deposits are found at Trondhjem and at Röraas. A small and irregular production of chromite was made some years ago, but this appears to have ceased until 1918, when 6,840 tons were mined.

Vogt has described fully the occurrence of the Norwegian chromites.

He states that the chromite of the Nordland district is associated with a peridotite of the saxonite variety composed of olivine and enstatite and in the Trondhjem district with a serpentine derived from a peridotite. He emphasizes the universal genetic connection of chromite with olivine-bearing

rocks and its absence in pyroxenites and amphiboles. Chromite occurs as a spotted ore and also as massive ore, and in various combinations of these forms; when disseminated in grains throughout the saxonite, it forms an ore varying in chromite-content from 3 to 75 per cent. In some places a chromite-dunite forms veins and stringers containing 50 to 60 per cent. of chromite: in other places, chromite-saxonite or pure chromite associated with chromite-saxonite forms well-defined lenses or veins in normal saxonite. In general the chromite peridotites show all variations in composition from 5 to 99 per cent. of chromite [43/pp. 681–2].

Portugal

Two kilometres from Bragança is a contact deposit of chromite between Archæan schist and a basic porphyry, from a few feet to 20 feet in thickness [38].

Russia

Chrome iron ore is found particularly in the soapstones and serpentines of the Ural Mountains. The principal localities are the banks of the Kamenka and of the Topkaja.

These ores have been classed under three heads:

1. Large granular masses in serpentine occurring in several places near Ekaterinburg, also eight miles from Bisserk and again near Kyschtinsk.

2. Those where the mineral is fairly disseminated through the rock, as at Mastrowaia, north of Ekaterinburg, and near Auschkul Lake

3. Chromite sand, usually occurring in the platinum and gold placer deposits, especially at Nizhne-Taghilsk in the platinum placers, and at Malo-Mostowskoi gold placers.

At Orenburg the mineral is found in masses. Bichromate factories exist at Elanbougi on the River Kama, at which about 2,000 tons of ore per annum were treated formerly, the production largely supplying the Russian market with bichromates.

Formerly about fifty separate chromite mines existed in the chromite-producing area, the combined output of which

reached 27,046 metric tons in 1905, but of late years no reliable statistics have been available. The Russian deposits include ores of good grade, but no trustworthy information as to the quality of the deposits generally is obtainable. The following are the analyses of two samples of Russian chromite:

No.	Cr_2O_3.	FeO.	Al_2O_3.	MgO.	CaO.	SiO_2.
1	51·62	17·94	14·52	13·15	·73	1·71
2	55·75	21·56	3·37	13·85	·60	5·37

[21/pp. 75–6]

Veins of compact to granular chromite have been discovered in serpentine, Northern Caucasus. An analysis of a sample gave 59 per cent. of chromic acid [39].

No doubt the chromite industry, like many other industries, has suffered by the political disorganization in Russia during recent years, but apparently a considerable output of chromite could be obtained under favourable conditions.

Yugo-Slavia

Serbia.—Ores of chromium occur at Ridjevstica at the foot of Mount Kopaenik on the Svebrnica in Serbia. The ore is said to occur in three forms—as compact granular chromite, as fine-grained chrome silicate, and as a chrome mineral that forms a constituent of decomposed mica schist. The mica schist is widely distributed in Roudin. Analyses of Serbian chromite from various sources indicate mineral of good grade, but, probably because of limited quantity, the production of the ore in Serbia has only been on a small scale [43/pp. 686–7].

Bosnia.—A small but steady production of chromite was maintained in Bosnia for over twenty years up to 1914, and, during the war, there was an unknown but doubtless an increased output. The chromite deposits occur in a belt of serpentine extending from Banjaluka and Varesh to the Serbian frontier in East-central Bosnia. The most important deposits are in the Dubostica Valley and extend over an area of about 114 square km. Other deposits occur in the Tribia and Krivaia Valleys. The ore is worked from open cuts, and occurs both

in irregular disseminated stringers and in bunches, as at Rakovatz, and in faulted layer-like bodies, as at Breznitza. Hand-picked lump ore carries from 49 to 54 per cent. of chromic oxide, but the disseminated ore is crushed and concentrated [43/pp. 685-6].

Chromite ore deposits are found at Raduscha in South-east Bosnia. These are said to be capable of yielding a large output, but require to be worked by modern methods to ensure commercial success [50].

Chromite was discovered in 1895 at Uskub in Kossovo Province, and a number of mines were being worked in 1904, the principal one being in the ownership of Patterson & Co., a well-known English firm. In 1911 the deposits of chromite at Oracha were estimated to be yielding 1,000 tons per annum, which was shipped to Austria. The best grade ores of this district contain about 55 per cent. of chromic oxide.

Chromite also occurs in Monastir Province [43/pp. 698-9].

ASIA

Asia Minor

In 1848, chromite was discovered near Brusa by Lawrence Smith, but the deposits were very slowly developed, and it was not until about 1860 that their full importance was felt in Europe and America [21/p. 8].

Since that period and up to 1903, Turkey supplied about half the world's consumption of chromite. In 1904 the output from New Caledonia surpassed that from Asia Minor, and in 1906 the Rhodesian deposits began to still further affect the output from Turkey.

Brusa.—Before the war the annual output was from 10,000 to 15,000 tons, and the possible output was said to be 200,000. The area is 15 miles long from east to west, and 8 miles broad from north to south [40]. At the Dagh-Ardi Mine there are two parallel masses from 33 to 50 feet in thickness, dipping 20°. The grade is from 44 to 52 per cent. chromic oxide. During the war the mine was managed by Gebrüder Röcklingen, of Mulheim, who erected an aerial tramway 14 miles long, and a dressing plant of a capacity of 30 tons per day.

The Karl-Yer Mine has produced 130,000 tons of chromite in 30 years. It is now owned by Krupps, who have exported 6,000 tons of chromite to Germany and Austria. The grade is 55 per cent. of chromic oxide. Near Harmandjik, and 7 miles from Dagh-Ardi, there are three mines formerly worked by Patterson Bros. of Smyrna. They were exploited by Krupps during the war and have an uncertain status at present. During the war, German firms exported from Brusa about 5,000 tons of ore for use in the chrome steel industry of Germany.

Smyrna.—Chromite occurs here in irregular masses, lenses or pockets, or in veins or seams from 6 to 10 feet in thickness, and usually dipping 45°. The grade of the ore varies from 40 to 52 per cent. of chromic oxide. Large quantities of ore are said to be available at the Kodjak Ali-Pasha Mine. During the war no chromite mines were worked in the Smyrna zone.

Adana and Konia.—In the neighbourhood of Mersipa are several chromite mines, which contain ore of from 50 to 51 per cent. of chromic oxide. The average annual output may be put at 1,000 tons. Before the war the ore was exported to France and Germany.

In July, 1919, the stocks at Makri amounted to 20,000 tons. The total stock of chromite in Asiatic Turkey was estimated in mid-July, 1919, to be 35,000 tons.

The following table shows some exports of chrome iron ore from Asia Minor before the war [41] [42]:

Pre-War Export of Chrome Iron Ore

	1910.	1911.	1913.
	Tons.	Tons.	Tons.
Austria-Hungary	485	1,196	—
France	1,955	5,480	4,573
Germany	—	1,356	457
Netherlands	3,762	300	2,834
United Kingdom	2,669	—	—
United States of America	2,800	7,815	18,200
Other countries	515	888	310
Totals	12,186	17,095	26,374

The output in 1914 amounted to about 30,000 tons. The

present annual production from Anatolia (or Asia Minor west of longitude 37° E.) is stated to be 18,000 tons [40/p. 29].

The methods of mining and the transport of the ore are generally extremely crude, and have contributed to a decline in the production. Another contributing factor in this decline is probably the fact that the State taxes amounted to 20 per cent. of the value of the ore mined, and an export tax of 1 per cent. was levied in addition.

Celebes (Netherlands East Indies)

It is reported in the *Board of Trade Journal* for October 3, 1918, p. 436, that deposits of chromite have been located to the north of Malili, on Lake Mantana, which it is believed will become economically productive. No particulars of the extent of these deposits are at present available.

Japan

Chromite is known to occur in many localities both in detrital deposits and *in situ* in serpentine.

Most of the deposits so far exploited were of small extent and therefore soon worked out. The most important mine now working is that of Wakamatsu in the Province of Hoki, where the ore averages 40 per cent. of chromic oxide and is easily worked.

On the upper courses of the Mukawa in the Province of Iburi, chromite occurs extensively both in serpentine and in gravels.

The production, so far as statistics are available, appears to have been annually about 2,000 tons of ore containing from 40 to 45 per cent. of chromic oxide for several years up to 1915, and for 1916, 1917 and 1918 it was about 8,000 tons for each year [34].

New Caledonia

Chromite has been known in this island since 1874. All the most important deposits are located amongst the mountains in the southern part of the island, and are contained in serpentine rocks.

In situ the chromite occurs as veins or included masses in serpentine bands or belts, the largest axis of the chromite ore-bodies corresponding with the general strike of the serpentine belts. The ore, when in masses, shows a distinct line of demarcation from the country rock, but chromite grains are disseminated through the rock for an appreciable distance from these well-defined bodies of ore.

A large quantity of alluvial chromite is also found, derived from the disintegration by weathering of the chromite-bearing rocks. This, contrary to similar deposits elsewhere, is of a sufficiently high grade to be worth exploiting, and it has furnished a large proportion of the total production.

Some idea of the large size of the New Caledonian chromite deposits may be obtained from the fact that one open cut has yielded upwards of 200,000 tons of ore.

Up to 1909, the Lucky Hit Mine had yielded 13,000 tons; the Pensée, 14,000 to 15,000 tons; the Josephine, 18,000 tons; and the Alice Louise, 10,000 tons [21/p. 78].

The production of chromite in the island for the ten years up to 1916 has averaged upwards of 50,000 tons per annum, and shows no signs of exhaustion. The freightage of the ore from New Caledonia to England was, prior to the war, 30*s.* per ton.

The earlier developments of the New Caledonian ore were small; but later a French company, "Le Chrome," gained control of the principal deposits and organized production on a large scale. The mineral areas are found in three different localities. The largest, to the north, includes the Tiebaghi Mine near Port Pagouméne, which yields ore of which samples carry up to 67 per cent. of chromic oxide. This mine produces between 4,000 and 5,000 tons of ore per month [21/p. 77]. Since 1911 the Tiebaghi Mine has been held by the Société la Tiebaghi, an organization registered in Paris. The Chrome Co., Ltd., has a contract under which it acquires ore.

The second area of importance is 20 kilometres south of Noumea and contains the Lucky Hit Mine. Here a chromiferous vein up to 15 metres in width is developed to a considerable depth below the surface. The ore is not of the highest grade and requires concentration [21/p. 77].

Exports of Chromium Ore from New Caledonia, 1910–17

In long tons (2,240 lb)

Exports to	1910.	1911	1912	1913.	1914.	1915.	1916.	1917.
United Kingdom	—	6,769	6,326	17,796	11,206	6,125	29,675	2,952 *
Australia	10,108	—	3,148	—	—	—	—	394 *
Belgium	—	—	1,573	—	19,794	—	—	—
France	8,097	1,476	6,993	3,819	5,791	14,783	17,148	185
Germany	—	—	6,242	—	6,616	—	—	—
Holland	6,533	11,857	12,247	15,574	9,669	—	30,229	3,763
Italy	—	5,570	—	—	—	—	—	1,476
Japan	—	—	—	—	—	—	14	3,793
United States	2,752	6,208	13,239	25,982	24,446	31,146	30,673	23,122
Unknown	—	—	—	—	—	1,182	—	—
Totals	27,790	32,879	49,773	63,351	77,522	56,239	107,739	35,685

* New South Wales only.

The third area, in the south of the island, had not at a recent date been much developed, but a railway had been built.

The table on the previous page summarizes the annual exports of chromium ore for recent years.

NORTH AMERICA

Cuba

No production of chromium ore in Cuba had been reported prior to 1918, but during that year the United States imported 8,821 tons of Cuban chromite.

Some years ago it was reported that a low-grade chromite deposit occurred at Canjete, on the north-eastern shore of Santiago de Cuba, but it was not until the European War, which created an increased demand for the mineral and made transport from producing to manufacturing centres difficult, that the possibilities of Cuba as a producer of chromite were investigated. According to a U.S. Geological Survey Bulletin [43/p. 723], this investigation has disclosed the existence of about a dozen groups of chromite deposits varying considerably in quality, size and accessibility.

One of the most westerly deposits is in the eastern part of the Province of Havana. Two groups are found in the Province of Matanzas and another group in the Province of Camaguey, a few miles north-east of Camaguey City. Other groups are in the Province of Oriente, one near Holguin and another south of Nipe Bay, and there are three groups in the mountains near the coast between Punta Gordia and Baracoa.

All the deposits examined are in serpentinized basic rocks. They are lenticular and in the form of tabular masses ranging in thickness from one foot to more than 50 feet, and reaching a maximum length of more than 200 feet. There is also a quantity of disseminated ore with the serpentine. The known resources of marketable chromite ore in Cuba range from 92,500 to 170,000 long tons, of which the largest proportion is contained in the deposits of the Caledonia, Cayoguan group and Potosi claims near the north-east coast of Oriente in a region not readily accessible. These are said to contain from 72,500 to 130,000 tons of ore.

The next largest group is near Camaguey. These deposits are easy of access, but the grade of ore is lower. They are estimated to contain from 20,000 to 40,000 tons.

In the eastern part of the island, enormous deposits of a chromiferous iron ore occur at several points, the most important being the Moa, Mayari and San Philipe deposits. These are found overlying serpentine, of which they are obviously a decomposition product, now forming a mantle of varying thickness, but averaging from 18 to 20 feet. The quantity of ore in these deposits is estimated from various sources at 3,000,000,000 tons. Exploration by borings indicate that the Moa deposit alone contains 1,307,000,000 tons [51/p. 418].

The character of the ore is indicated by the analyses of many hundred samples which show the following results:

	Per cent.
Fe	40 to 50
Ni	0·5 to 1
Cr	1·5
SiO_2	2 to 6

Phosphorus low and sulphur negligible.

The iron is present partly as hæmatite and partly as limonite, the former predominating in the upper layers of the deposit and the latter near the base [44]. These ore deposits are being extensively worked, and the exports of ore to the United States for the four years ending 1913 amounted to an average of 1,403,110 tons per annum [25].

Pig-iron produced from these ores contains in percentages: chromium 2·80, nickel 1·50, manganese 0·87, and is of special value for certain casting mixtures. Mayari steel, which is a well-known product of these ores, contains from 0·10 to 0·40 per cent. of chromium, from 1·00 to 1·50 per cent. of nickel, and from 0·50 to 0·80 per cent. of manganese.

In the production of this steel, the greater portion of the chromium is intentionally oxidized and eliminated in the slag [5].

GUATEMALA

There are deposits of chromite reported at Potrero, Carillo and Patachu in Jalapa County. These are being worked

and shipments of ore are made to New York. About 2,000 tons of ore were exported during 1918 [45], and 3,000 tons of 56 per cent. ore in 1919.

NICARAGUA

This country possesses chromite deposits, but little is known about them.

Some mining is carried on and a small quantity of ore is shipped to the United States [34/p. 92].

UNITED STATES

Deposits of chromite occur in many parts of the United States. From 1828 to 1850 the mines of Maryland and Pennsylvania supplied the world with chromite, and the Wood Mine, of Lancaster County, Pa., yielded about 95,000 tons of ore. Afterwards there was severe competition, first with Asia Minor, and later with California. No production is reported from Pennsylvania at present, and from 1880 to 1917 no rock-chrome was mined in Maryland, but there was a small and irregular production (about 25 tons annually on an average) of sand-chrome throughout those years. The chromite-bearing sands are found either within or close to the serpentine areas. The concentrate is exported to Europe, where it is used to set the colours of paintings on fine porcelain ware, the selling price averaging about twice that quoted for chrome ores [46].

By referring to the table on p. 5, it will be seen that for the four years preceding the war the output of chromium ore from the United States was quite insignificant, but in 1915 there was a decided increase in production; in 1916 the United States became third on the list as producers of chrome ore; in 1917, with a tonnage of 43,723, which is rather more than one-third of the production of the British Empire, she exceeded the production of New Caledonia, and so occupied the second place on the list. In 1917 by far the greater quantity of chrome ore came from California; Oregon supplied about 7,500 tons, and smaller quantities were shipped from Maryland, N. Carolina, Washington and Alaska. In

1918 there was an increase of 88 per cent. in quantity, and of 275 per cent. in value as compared with the previous year. The production of 1919 was only 3,900 tons.

Alaska

Chrome ore deposits occur at Red Mountain on the Kenai Peninsula. These have been known for some years, but owing to insufficient market inducements, were not worked until recently.

The demand for chromium for steel and non ferrous alloys has resulted in the exploiting of these deposits although the cost of transport of the ore is high. About 1,000 tons of ore, averaging from 46 to 49 per cent. of chromic oxide, were shipped in 1917, and about an equal quantity remained to be mined above high-water mark. There are extensive ore resources between high- and low-water mark, but the difficulties of mining the ore are great.

The ore is sent by water to Seattle, and is shipped from there to the eastern states. The cost of transport to Seattle is 3·50 dollars, and the freight from Seattle across the continent is 12 dollars per ton. Obviously only high prices will permit of transport at this cost.

At Red Mountain, 16 miles north-east of the above deposit and 6 miles from the nearest tidewater, other bodies of chromite occur. They have not yet been worked, but are estimated to contain approximately 200,000 tons of ore [43/p. 621].

California

Prior to 1916 California was for many years the only state producing chromite. In 1915 the output came principally from Shasta and Fresno counties, whilst Butte, Del Norte, Glenn, Nevada, Tehama and Tuolumine counties were minor contributors [47].

Chromite occurs in thirty-two counties of the state, and in quantities sufficient to be won in twenty-four counties. During 1916–18 ore was actually being shipped from twenty-two counties. In the following notes [48] the counties are

taken in alphabetical order, those from which large quantities of chromite have been or are being shipped being marked *.

Alameda.—Deposits of chromite occur in Cedar Mountain. It is reported that over 3,000 tons of ore have been mined from this locality.

Amador.—In the Ione district there is a small production, and new discoveries have recently been reported.

**Butte.*—This county contains two considerable deposits of chromite, one at the Intake on the Western Pacific Railway and the other at Berry Creek. A large quantity of ore has been shipped from Butte since 1915.

Calaveras.—Near Valley Springs, a series of six lenses of chromite occur within a distance of 700 feet along the strike. The largest lens is about 50 feet long and 10 feet wide. These lenses occur in the serpentine, 25 feet from its contact with the amphibolitic schist, and lie nearly parallel with the contact. There have been recent shipments of ore from this county.

Colusa.—No ore has been shipped from this county, but there have been recent developments on some of the deposits.

**Del Norte.*—The chromite zone in this county forms a portion of the Klamath Mountain region. The ore occurs as lenses in serpentine and also as contact lodes between diorite (? greenstone) and serpentine. Chromite mining has recently been active at French Hill, Gordon Mountain and Monumental.

**El Dorado.*—Chromite occurs in chimneys and lenses in serpentine. In July 1918 there were five concentrating plants in operation. The Pilliken property, of the Salmon Falls district, has been considerably developed and is leased to the Noble Electric Steel Co. It is estimated that 50,000 tons of chromite ore exists in the vicinity of Salmon Falls and Negro Hill.

**Fresno.*—This county has continued to be an active producer of chromite since 1915, the annual output amounting to several thousand tons of ore.

**Glenn.*—A considerable production of chromite from this county has been reported.

Humboldt, Lake and Mariposa.—Some ore has been recently shipped from these counties.

Mendocino, Monterey, Napa, Nevada and Placer.—Chromite occurs in all these counties, but from the first two there is no output, and only small shipments from the others.

Plumas.—A lens of solid chromite 4 feet wide in the centre, and 80 feet long, occurs on the east bank of the Middle Fork of the Feather River. It strikes N.S. and pitches 80° W. in a fine-grained metamorphic limestone. A small quantity of ore has recently been shipped from the county. This is said to be the only instance known of chromite in quantity being found in limestone rock.

San Benito.—Chromite deposits are being developed, but so far only a small quantity of ore has been shipped from this county.

**San Luis Obispo.*—Two mines in this county were recently shipping from 100 to 200 tons of chromite per month. The California Chrome Co. has a 50-ton concentrating mill on one property.

Santa Barbara, Santa Clara.—There are recent developments in, and there have been small shipments of ore from, both these counties.

**Shasta.*—A part of this county is in the Klamath Mountain range. Several deposits of chromite occur in this range, but the most noteworthy is that of the Little Castle Creek (formerly known as the Brown) Mine, owned by the California Chrome Co. From one lens 15,000 tons of ore had been shipped from 1900 to the end of 1916. The ore is massive and of high grade. The country rock is enstatite-peridotite in part altered to serpentine. Amphibole asbestos is associated with the ore-body on one wall, and a talc gouge up to 2 feet thick on the other wall. Beautiful wine coloured crystals of *kammererite* (chromium chloride mica) occasionally occur in vesicles or vugs in the chromite.

Sierra.—A little chromite has recently been shipped from this county.

**Siskiyow.*—This county is also in the Klamath Mountain region. At Callahan, *uvarovite* (green chrome-garnet) occurs as a secondary mineral. A large quantity of ore has recently been shipped from the Coggins deposit.

Sonoma and Stanislaus.—The chromite deposits of the former

county have proved to be small. The latter county produced about 2,000 tons of chromite from 1916 to 1918.

**Tehama.*—Chromite occurs in this county as lenses, and in finely disseminated particles in decomposed serpentine. One mine has an aerial tramway and a mill for concentrating the low-grade ores. The Noble Electrical Steel Co. is mining one large deposit of chromite.

Trinity.—This county is also in the Klamath Mountain region, but parts of it are remote from transportation, so that hitherto little ore has been shipped from the deposits, which are known to occur.

Tulare.—A considerable quantity of chromite has, in the past, been shipped from the Vaughn Ranch deposit, which is now worked out, but shipments of ore from other mines in the county have been reported in recent years.

**Tuolumne.*—There was a large output of chromite from this county in 1918.

Montana

In Montana, a chromite deposit assaying from 32 to 47 per cent. of chromic oxide has recently been discovered 32 miles from Big Timber. Other deposits occur on the Boulder River, Sweet Grass County.

North Carolina

In North Carolina, chromite deposits occur at Mine Hill, Yancey County, near Webster, Jackson County, and near Big Ivey Creek, Buncome County. In the last locality secondary ores (chromite sand) occur as well as rock chrome. The latter contains 48 per cent. and the former can be concentrated up to 50 per cent. chromic oxide.

Oregon

The State of Oregon commenced to produce chromium ore in 1916 with 3,000 tons, in 1917 the production increased to 6,700 tons.

Many deposits occur in Josephine County. At Golconda, a series of chromite lenses occur from 15 to 60 feet wide in

Imports of Chromium Ore into United States

In long tons (2 240 lb.)

Imports from	1911.	1912	1913	1914	1915	1916.	1917.	1918.
Canada	15	15	—	533	350	15,783	14,749	20,949
British S. Africa	3,400	—	—	—	2,850	35,650	16,050	521
Australia	—	—	—	—	—	1,500	1,486	15,976 *
Greece	4,500	7,513	—	8,450	4,805	8,805	3,400	—
Portugal	—	15,455	5,000	—	—	—	—	—
Turkey (Asia)	4,500	11,030	14,850	14,830	5,700	—	—	—
French Australasia	8,017	9,600	6,620	25,070	18,410	37,174	34,807	25,761
Portuguese Africa †	16,318	5,100	24,000	30,000	15,430	7,850	42,800	8,000
Other countries	449	1,250	322	58	—	7	34	28,935 ‡
Total	38,149	50,963	49,792	79,842	47,551	107,069	113,326	100,142
Value	£1,101	£2,320	£4,980	£3,595	£2,252	£10,213	£42,485	£99,532

* As reported probably almost all New Caledonian ore.
† Rhodesian Ore shipped from Beira.
‡ Includes 17,854 tons from Brazil; 8,821, from Cuba, 1,193, from Guatemala, and 1,063 from British sources not specified.

a belt of country about 300 feet wide. Ore carrying from 38 to 45 per cent. of chromic oxide is shipped as mined, and the lower grade ore is concentrated at the rate of 30 tons per day. This deposit has already yielded 3,000 tons of 40 per cent. ore.

Wyoming

Chromite deposits also occur in this state, and shipments on a small scale were made in 1918.

Imports

The table on the previous page gives the imports of chromium ore of the United States for the years 1911–18 [49].

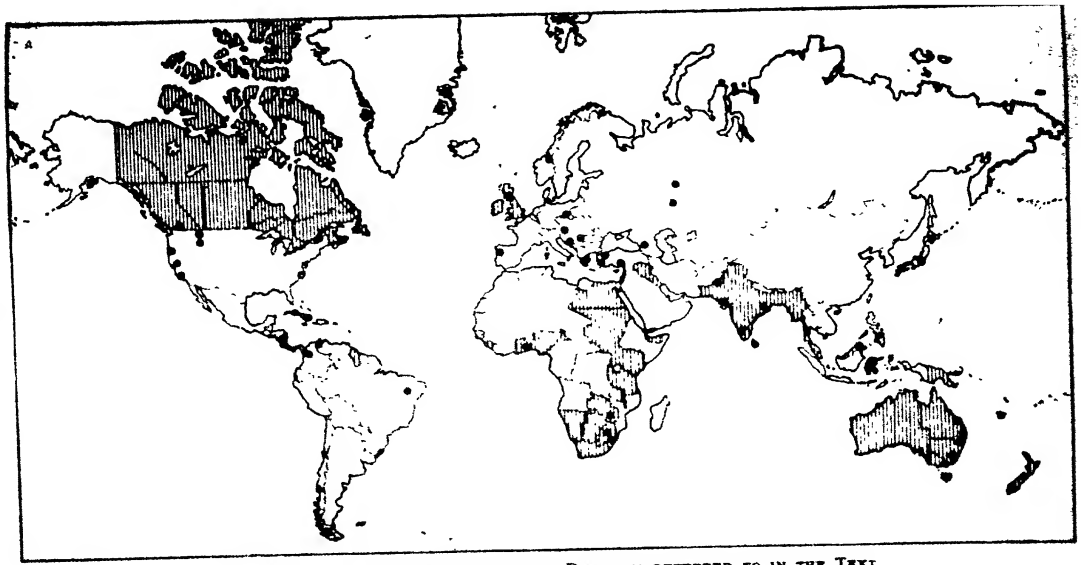
SOUTH AMERICA

Brazil

Brazil is reported to possess valuable chromite deposits north-west of Bahia. No production had been reported up to the end of 1917, but in 1918 the United States imported 17,854 tons of chromite from this country [49/p. 73].

Colombia

Large deposits of chromite ore are stated to exist at Antioquia, where the ore has been used as a building stone. There are no particulars of these deposits having been mined [21/p. 74].



MAP SHOWING THE CHROMIUM-BEARING DISTRICTS REFERRED TO IN THE TEXT
(British Empire and Protectorates shaded)

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